Past-paper walk-through

Uniform electric fields ▪ 18.2

eXercise

Questions in this set

- 9702/42 J25 Q6 ▪ 11 marks
- 9702/42 M25 Q6 ▪ 11 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 6

9702/42 J25 ▪ Q6 ▪ 11 marks

Two parallel metal plates X and Y are separated by a distance of 0.041 m, as shown in Fig. 6.1.

There is a vacuum between the plates. An electron is at rest at the centre of plate X. A potential difference (p.d.) of 58 kV is applied across the plates. This causes the electron to accelerate towards plate Y.

(a) On Fig. 6.1, use the symbols $+$ and $-$ to indicate which of plates X and Y is the positive plate and which is the negative plate. **[1]**

(b)(i) Calculate the electric field strength *E* between the plates. Give a unit with your answer. **[2]**

(b)(ii) Determine the acceleration of the electron. **[2]**

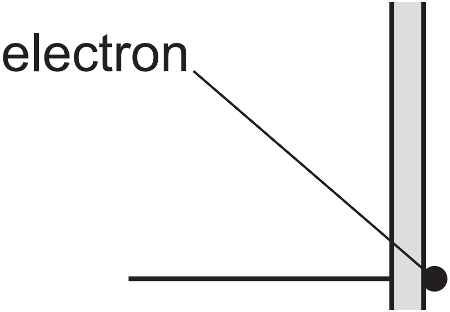
(c)(i) Show that the minimum wavelength of these electromagnetic waves is 21 pm. **[3]**

(c)(ii) State the region of the electromagnetic spectrum that contains these waves. **[1]**

Question 6

(c)(iii) Explain how these electromagnetic waves may be used to form images of internal body structures. **[2]**

Question 6



Solution 6

(a)

Mark scheme

- plate X marked as negative and plate Y marked as positive **B1**

Solution 6

(b)(i) Worked steps

Between parallel plates the field is uniform, and its strength is the p.d. divided by the separation.

- $E = \dfrac{V}{x} = \dfrac{58 \times 10^3}{0.041}$
- $E = 1.4 \times 10^6\ \mathrm{N\,C^{-1}}$

Solution 6

The question asks for a **unit** and it carries a mark: $\mathrm{N\,C^{-1}}$ or the equivalent $\mathrm{V\,m^{-1}}$ — the second makes the formula obvious. Put the separation in **metres**; 41 mm entered as 41 gives an answer a thousand times too small.

Mark scheme

- E $=$ V / x **C1**
- $=$ (58 $\times$ 103) / 0.041
- $=$ 1.4 $\times$ 106 N C–1 **A1**

Solution 6

(b)(ii) Worked steps

Newton's second law, with the electric force as the only force acting.

- $F = eE$ and $F = ma$, so $ma = eE$ and $a = \dfrac{eE}{m}$.
- $a = \dfrac{1.60 \times 10^{-19} \times 1.41 \times 10^{6}}{9.11 \times 10^{-31}}$
- $a = 2.5 \times 10^{17}\ \mathrm{m\,s^{-2}}$

Use the **electron's** mass, and carry the unrounded field strength forward (1.41, not 1.4).

Solution 6

An acceleration of 10^{17} m s^{-2} is not a mistake: the electron is extremely light, and this is exactly why an electron gun brings one to a large fraction of the speed of light across a few centimetres.

Mark scheme

- ma = eE **C1**
- a = (1.60 × 10–19 × 1.41 × 106) / (9.11 × 10–31)
- = 2.5 × 1017 m s–2 **A1**

Solution 6

(c)(i) Worked steps

The shortest wavelength is produced when an electron gives up **all** its kinetic energy to a single photon, so equate the energy it gained in the field to the photon's energy.

- Energy gained crossing the p.d.: $E = eV$.
- Photon energy: $E = hf$ with $c = f\lambda$, so $E = \dfrac{hc}{\lambda}$.
- Equate: $eV = \dfrac{hc}{\lambda}$, giving $\lambda = \dfrac{hc}{eV}$.
- $\lambda = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.60 \times 10^{-19} \times 58 \times 10^{3}} = \dfrac{1.99 \times 10^{-25}}{9.28 \times 10^{-15}}$
- $\lambda = 2.1 \times 10^{-11}$ m $= 21$ pm, as required.

Solution 6

This is a *show that*, and one of the three marks is specifically for the **conversion from metres to picometres** — 1 pm $= 10^{-12}$ m, so 2.1×10^{-11} m is 21 pm. Stopping at the metres answer leaves a mark on the table.

Solution 6

Watch the kilovolts: 58 kV is 58×10^3 V. And note *why* this is a **minimum** wavelength — most electrons lose their energy in several steps and make longer wavelengths; only the one that converts everything at once reaches this limit.

Mark scheme

- eV $=$ hc / λ or eV $=$ hf and f $=$ c / λ **C1**
- (1.60 $\times$ 10–19 $\times$ 58 $\times$ 103) $=$ (6.63 $\times$ 10–34 $\times$ 3.00 $\times$ 108) / λ **M1**
- clear conversion from m to pm leading to λ $=$ 21 pm **A1**

Solution 6

(c)(ii)

Mark scheme

- X-rays **B1**

(c)(iii)

Mark scheme

- Any two points from:
- ▪ waves are passed into structure and transmitted waves detected
- ▪ different parts of the structure absorb different fractions of energy
- ▪ difference in detected / transmitted intensities used (to form image) **B2**

Question 6

9702/42 M25 ▪ Q6 ▪ 11 marks

6 An electric field and a magnetic field are used to form a velocity selector. Charged particles, called ions, pass into a region of uniform electric and magnetic fields that is between parallel plates, as shown in Fig. 6.1.

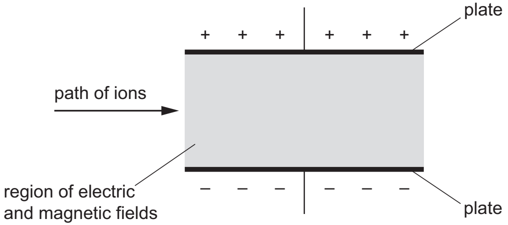


Fig. 6.1

Question 6

(a) The potential difference (p.d.) between the plates of the velocity selector is V. The separation of the plates is d and the magnetic flux density is B.

Show that the speed u of ions that pass undeviated through the velocity selector is given by

$$u = \frac{V}{Bd}.$$

Question 6

[2]

(b) Positive ions with kinetic energy 4.1×10^{-17} J and mass 3.2×10^{-27} kg pass undeviated through the velocity selector when V is equal to 980 V and d is equal to 3.6×10^{-2} m.

Determine B.

(c) A proton passes undeviated through the velocity selector.

An alpha particle enters the velocity selector at the same speed as the proton.

State how the expression in **(a)** predicts that the alpha particle also passes undeviated through the velocity selector.

Question 6

(d) By reference to Fig. 6.1 and to the forces acting on a positive ion, determine the direction of the magnetic field. Explain your reasoning.

(e) The positive ions in **(b)** enter the velocity selector with greater kinetic energy.

On Fig. 6.1, sketch the path of these ions. [2]

[Total: 11]

Solution 6

(a) Worked steps

A velocity selector works because the two forces on a moving charge point in opposite directions, and only one of them depends on the speed.

- The **magnetic** force on a charge moving perpendicular to the field is $F_B = Bqu$ — it grows with the speed.
- The **electric** force between the plates is $F_E = qE$, and with a p.d. V across a separation d, $E = \dfrac{V}{d}$, so $F_E = \dfrac{qV}{d}$ — it does not depend on the speed at all.

Solution 6

A particle passes straight through only when the two balance:

- $Bqu = \dfrac{qV}{d}$
- The charge q cancels, leaving $u = \dfrac{V}{Bd}$.

Solution 6

Two things worth saying out loud in the answer, because they are what the marks are for: the forces must be **equal and opposite**, and q cancelling is why the selector picks a speed regardless of the charge or the mass of the particle. That is the whole point of the device.

Mark scheme

- FB = FE
- either: Bqu = qE and E = V / d leading to u = V / Bd
- or:
- Bqu = qV / d leading to u = V / Bd
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Solution 6

(b) Worked steps

Substitute into the expression just derived, with every quantity in SI units.

- $u = \dfrac{V}{Bd}$, so put the p.d. in volts, the flux density in tesla and the plate separation in **metres**.

Solution 6

The separation is the quantity most often left in millimetres; doing so makes the selected speed a thousand times too small. Check the answer against light: a velocity selector for charged particles gives something well below 3×10^8 m s^{-1}, so a result above that means a unit was missed.

Mark scheme

- EK = ½mu2
- u = √[(2 × 4.1 × 10–17) / (3.2 × 10–27)]
- = 1.6 × 105 m s–1
- B = 980 / (3.6 × 10–2 × 1.6 × 105)
- = 0.17 T

Solution 6

(c)

Mark scheme

- expression is independent of mass and charge

Solution 6

(d)

Mark scheme

- either: electric force is downwards so magnetic force is upwards
- or:
- no resultant force so magnetic force is upwards
- (positive ions so) current is from left to right
- from (Fleming's) left-hand rule, magnetic field is into the page

Solution 6

(e)

Mark scheme

- curved path inside plates with consistent direction of curvature and with no discontinuity at entry or in curvature
- direction of deflection is upwards